

## Energy efficiency by thermal spraying

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### Abstract

Machines used by the basic industries of Russia (metallurgy, oil-gas processing and power engineering) are characterized by high metal consumption, which in turn lead to high energy consumption. Their service lives increase and their worn parts are restored by means of low-cost materials for restoration. The processes of Thermal Spraying (TS) are more effective than alternative methods in restoration and increase in service life. Such methods include electroplating, chemical and thermal processing. The results of research and experience have proven this. At the same time, the load on the environment is reduced in comparison with the alternatives by decreasing emissions.

Based on OEM publications and our own experience, we analysed the efficiency of TS processes. Plasma spraying was excluded from consideration since it has no real alternative for refractory oxide coatings which are mainly used for gas turbines and jet engines. By the criteria of the coating's quality, performance and cost arc of spraying, flame spraying, HVOF/HVAF, cold spraying and detonation spraying were compared. Commonly used materials for TS, such as metals and carbides in metal bond (cermet), were examined as sprayed materials.

This paper shows that a combination of activated arc spraying and HVAF for producing wear and corrosion-resistant coating is a rational variant with respect to a wide variety of parts for the aforementioned industries.

Examples of resource-saving in metallurgy, oil-gas processing and power engineering are shown based on our own TS experience in material, equipment and technology development.

*Keywords: resource saving, thermal spraying, HVAF, HVOF, arc spraying, metallurgy, power engineering, service life increase.*



## 1 Introduction

There are large losses of equipment units from wear and corrosion due to high impacts in the basic industries of Russia, such as power engineering, gas–oil and metallurgy. This is intensified by the low residual life of equipment in operation. In power engineering the share of overtime working machines is, for example, 60% [1].

The cost of equipment repair represents a significant share in the structure of the production cost. In metallurgy, depending on the process stage, the repair costs reach 20% of the total production cost [2]. In mechanical engineering the share lays within 6–20% [3]. Russian coal-burning power plants produce about one third of total power consumption. Here, the share of equipment repair costs is 12% of the cost of the electricity generated [4, 5]. The cost of the work to restore parts is about 30% within the total repair cost [2].

The costs level in absolute terms is given in the following. Metallurgical industry share in Russian GDP is about 5% [6]. According to the Morgan Stanley bank “Report on the global economy” in 2012, Russia's GDP in 2012 was \$2.117 trillion [7]. Based on the above proportions, the annual cost of restoration works in Russian metallurgical plants is about \$6.4 billion. In 2003 expenses for the repair of equipment in the coal-burning power plants amounted to \$1.1 billion [5]. This corresponds to the total cost of the repair of the equipment in the power engineering to the order of \$3.5 billion, including the \$1.2 billion restoration works.

Experts consider that the possibility for a significant equipment life increase due to improving the properties of structural materials and by introducing more advanced technology solutions is almost exhausted [8].

Thus, the market of the parts restoration work in metallurgy and power engineering of Russia is estimated at \$7–7.5 billion. Based on Russia's share of production in these segments, the world market is more than an order of magnitude.

In addition to the direct effect, the environmental load is significantly reduced by lowering the consumption of materials and energy. The material's value for parts restoration is comprised of 1–5% of the total parts mass costs and the share of electric energy consumption for the production of metals is 28% of total industrial consumption [6].

## 2 State of art

### 2.1 Prospective ways for increasing service life

In many areas the use of Thermal Spraying (TS) coatings is more effective than the alternative methods of surface treatment (electroplating, chemical heat treatment, etc.) according to the criteria of reliability, process ability and environmental friendliness [14]. Thus, the load on the environment is reduced, which is due to the lowering of emissions in comparison with the alternatives.



In the case of Russia the economic effect of TS application in metallurgy and power engineering can be estimated as the following: \$7 billion  $\times$  0.1  $\times$  0.3 = \$210 million. Here, it is assumed that the cost of work to restore parts accounts for 30% of the total repair costs [2] and the share of TS was taken as 10% of the repairing market.

In world practice, TS is accepted as a reliable industrial technology. The likelihood of a machine's life being increased against wear and corrosion, by means of TS, lays within 2\_8 times as much. In 2011, the total world volume of TS production was \$7.5 billion [9].

Our experience of TS shows that the share of the coating cost is 20–40% of the total cost of a new part.

The share of the cost of TS materials is 50–80% of the cost of final coating. So, the urgent purpose now is to develop materials for TS at lower costs, while maintaining or improving the characteristics of the coatings.

In addition, TS methods such as Plasma, Flame (low and high velocity) and Cold- and Arc Spraying differ by their specific expenses for obtaining coatings due to the different outputs and deposition efficiencies (DE) of the material. Thus, the coatings produced by typical Arc Spraying are 3 to 10 times cheaper, as compared with alternatives. Therefore the purposeful development of materials for cheaper methods is required.

Domestic and foreign studies show that in the case of the application of nanostructured and amorphous coatings, the resource of equipment increases by 4 to 7 times in comparison with the coarse analogs. Its properties are increased as follows: the strength of the metal by 1.5 to 3 times, the micro hardness by 2 to 7 times, corrosion resistance by 10 to 12 times [6 (Appendix 7), 8, 10 and 11].

Close attention is paid to the development of cored wires for Arc and Flame Spraying. Their use allows for obtaining nanostructured coatings of complex alloying systems by the simplest method [12, 13].

So far the task of developing new materials and technologies of TS is urgent. Solving that problem can significantly increase the life of equipment operating under extreme mechanical, thermal and chemical loads, while providing a high-quality coating and spraying productivity at a lower cost.

Today a share in plasma spraying (PS) accounts for 45% among other TS methods [9]. This method does not have any adequate alternatives for fabricating coatings of refractory oxides (alumina, chrome oxide, zirconia, etc.) in the manufacturing of gas turbines and jet engines. In addition to this, it is traditionally used in other industries, such as steel production, gas-oil, chemistry, etc.

However, nowadays other TS methods in many applications ensure a similar level of coating quality, while reducing overall costs and improving process ability. The example of Korea, which is one of the world leaders in terms of economic growth, is indicative. Here the share of PS applications is 30% lower than in the rest of the world, due to a growth in the use of other methods [15].

On the basis of OEM publications we evaluate the suitability of TS methods for producing coatings. Only metals and cermets (carbide and metal bond) were considered as typical sprayed materials against corrosion and wear. The analysis

excluded oxides which are successfully sprayed by PS. Performance, relative cost and quality of coatings were taken as the selection criteria.

According to the criteria of performance and cost (Figs 1, 2) Arc Spraying (AS) and High Velocity Oxygen/Air–Fuel Flame Spraying (HVOF/HVAF) were chosen for further consideration.

TS techniques which were excluded from consideration are regularly used. For example, Flame Spraying (FS) is widely spread due to the simplicity of equipment, Cold Spraying (CS) – to produce coatings of low melting metals and Detonation Spraying (DS) – to produce coatings of high density. However, for

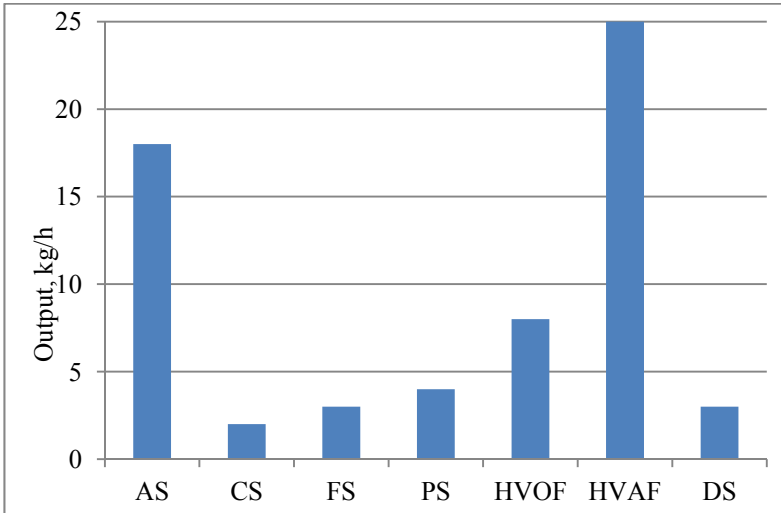


Figure 1: Output of main TS methods [17–20].

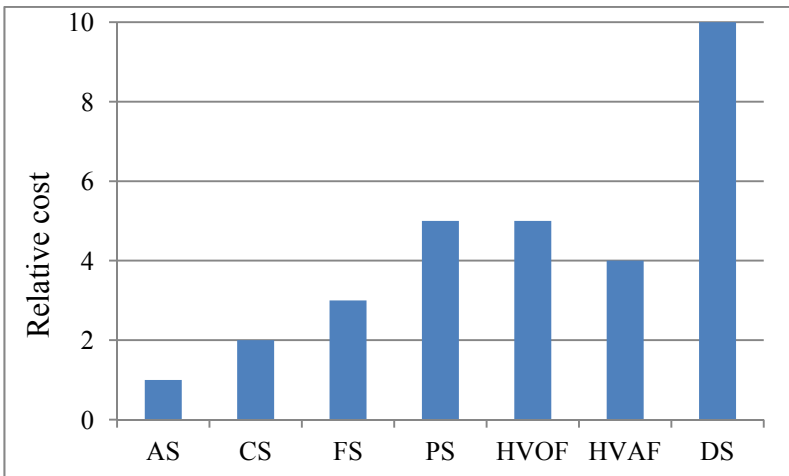


Figure 2: Relative cost of coatings producing by various TS methods [17–20].

many practical purposes the adopted limitations are critical and do not allow for them to be used as production technology. The world's TS application tendency is as follows: the share of FS decreased by 2.5 times from 1999 to 2010, now the share of CS is approximately 3% [9]. This confirms our conclusion.

## 2.2 Selection of the Arc Spraying (AS) method

AS is used for protection against corrosion and wear, i.e. elements of thermal stations and metal constructions as well as for producing bimetallic products. The cost of AS coating is 3 to 10 times lower than in the case of other TS methods. This is caused by its high thermal efficiency and productivity, low cost of sprayed materials and ease of maintenance.

The analysis showed that the increasing share of AS applications by 1.5 to 2 times is possible due to the materials and technology. However, the insufficient quality of coating (i.e. porosity, degree of oxidation) and low DE limits the use of this simple and cheap TS method.

The process of Activated Arc Spraying (AAS) was developed based on the study of the physical-chemical regularities of AS [21]. A purposeful influence on the arc-burning zone by reducing carrier gas is formed here by the combustion products of a propane–air mixture. The average level of AAS parameters is 40% higher in comparison with both domestic and foreign AS guns, i.e. the spray angle is  $10^\circ$ , DE is 85%, the degree of coating oxidation is 2.1–2.9%, the particle velocity is 140–500 m/s and the porosity is 2% (steel) [23–25]. The productivity and thermal efficiency of the process remained at the AS level. An appropriate gun and a set of typical technologies were put into practice (see fig. 3) [22].

Specially designed cored wires for AAS are commercially available for wear (500–700 HV100) and heat-resistant (up to  $700^\circ\text{C}$ ) applications [26].



Figure 3: Steel wire being sprayed by an AAS gun.

### 2.3 Comparison of HVOF/HVAF methods

The analysis of OEM publications [27–37] has shown that the presence of several types of equipment differ by carrier gases, modes of heated parts cooling, powder feeder design and outputs. Oxygen is used as an oxidant in HVOF guns and air is used for it in HVAF guns (fig. 4).

Basic HVOF models and their manufactures are the following: JP-5000/8000, TAFA-Praxair (JP); DJ 2600/2700, Sulzer Metco (DJ). HVOF models of other manufacturers operate by similar schemes, but with patented differences in design. For example, JP-8000 analogues are WokaStar (Sulzer Metco) and K2 (GTV). No significant differences in the parameters of the basic models and analogues were observed.

Basic HVAF models are the Intelli-Jet SB 9300/9500 (IJ), the M2 Spray Gun and the M3 Supersonic Spray Gun (hereinafter M2/M3). The main manufacturer is UniqueCoat Technologies.

IJ and M2/M3 units are more convenient in maintenance due to the lower costs of consumables and their convenient cooling medium (see Table 1).

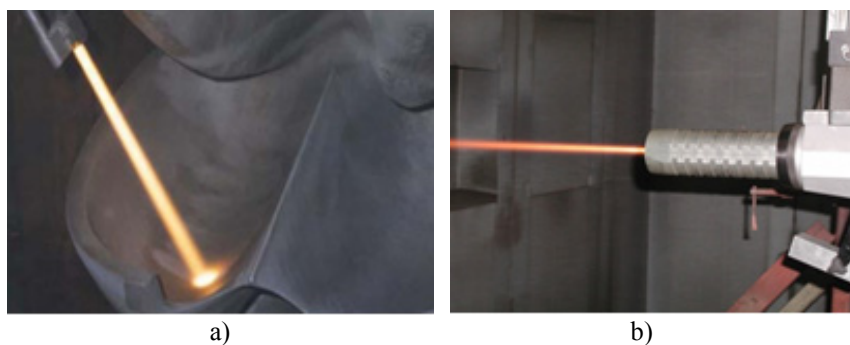


Figure 4: Basic models for spraying: a) HVOF, JP-8000; b) HVAF, M3.

Table 1: Consumption of materials per 1 hour of operation.

Consumables		IJ, M2/M3	JP	DJ
Oxygen, m <sup>3</sup>		-	60	18
Air, m <sup>3</sup>		300	-	23
Fuel	Type	Propane/Propylene	Kerosene	Propylene
	Output, kg	30	21	17
Nitrogen, m <sup>3</sup>		0.96	1.2	1.08
Cooling water, m <sup>3</sup>		-	1	0.72

All plants are of stable durability whilst operating, they are equipped with remote computer control units and comply with electrical and fire safety.

IJ, M3, JP, DJ provide approximately the same level of coating properties, i.e. porosity < 0.2%, adhesive strength of > 70 MPa and oxygen content in the coating < 1%.

M3 provides a particle velocity of 1000–1200 m/s. This is 30 to 40% higher than that of JP, DJ and previous HVAF models (M2 and IJ). This leads to a high contact pressure at the drop impact on the substrate, which in turn results in an increased adhesion and cohesion. The temperature of carrier gas through the use of air as the oxidant is lower at HVAF. As a result the particle's temperature is reduced. This in turn leads to less decarburization of primary carbides in the cermet. Furthermore, a combination of the particle's maximum velocity and their minimal heating at a working distance in the case of M3, is favorable for reducing thermal stresses in the coating. Joint local influence of these factors leads to an increased wear resistance of HVAF-coatings vs. HVOF ones (Fig. 5). IJ, M3 and DJ2700 are of the highest deposition efficiency. The output of IJ and M3 is 2 to 2.5 times as high (spraying powder WC-10Co-4Cr, fraction (-45 + 10) (see Fig. 6).

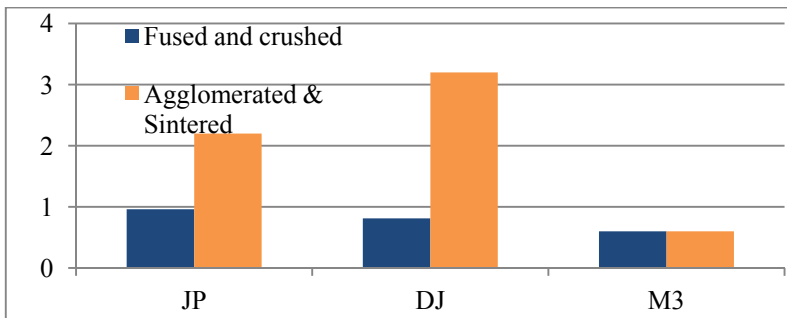


Figure 5: Comparative abrasion wear ( $\text{mm}^3/1000$  rotations) of HVOF/HVAF WC-10Co-4Cr coatings of different morphology, on a “rubber disk vs. flat sample” test according to ASTM G65, corundum abrasive 360–500 mkm.

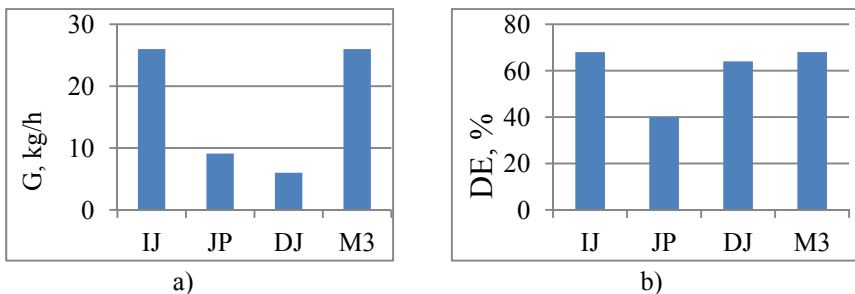


Figure 6: Basic HVOF/HVAF plants: a) output; b) DE.

The joint effect of higher DE, output and lower maintenance costs of consumables (see Table 1) results in lowering the specific cost by 1.6 to 2.5 times for the IJ and M3 (see Fig. 7).

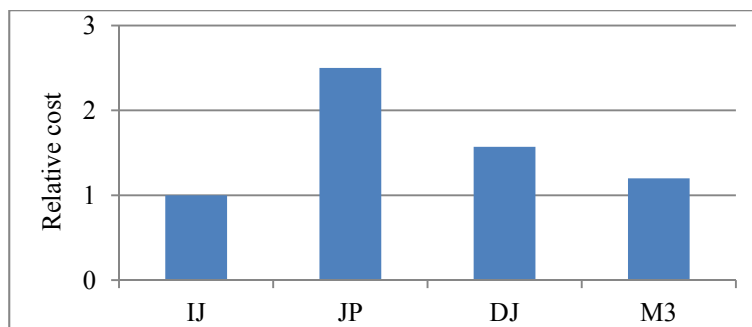


Figure 7: Relative cost of HVOF/HVAF coatings.

### 3 Applications

AS is used for the restoration of shaft journals that connect with ball bearings and sliding bearings. Bearing sockets and plungers are also very typical applications here. AS is also applied for anticorrosion coatings of Al, Zn, corrosion-resistant and heat-resistant steels and it is possible to produce bimetallic parts such as “steel-bronze” and “steel-babbitt”. Characteristics such as the part title, its features, the coating material and the coating thickness are illustrated in Fig. 8.

High quality HVAF-coatings can be successfully used in severe wear and corrosive conditions in power engineering, metallurgy, aviation, oil and gas processing, the paper industry etc. Various applications are shown in Fig. 9.

### 4 Conclusions

The increased service life of equipment within the basic industries of Russia allows for reducing the environmental load significantly by reducing the consumption of materials and energy.

In many fields of applications TS processes are more effective for a restoration and service life increase than alternative methods, such as electroplating, chemical and thermal processing, according to the criteria of reliability, process ability and environmental friendliness. Thus, in comparison with the alternatives, the load on the environment is lowered due to the reduction of emissions. In world practice TS is accepted as a reliable industrial technology. It ensures a machine’s life is increased and protected against wear and corrosion by 2–8 times.



Analysis and examples of TS applications show that the combination of Activated Arc Spraying and High Velocity Air-Fuel Spraying is preferable for spraying metals and cermets by the criteria of performance, quality and the specific costs of the coating produced. This covers a wide range of antiwear and anticorrosion applications in power engineering, metallurgy, oil-gas etc.

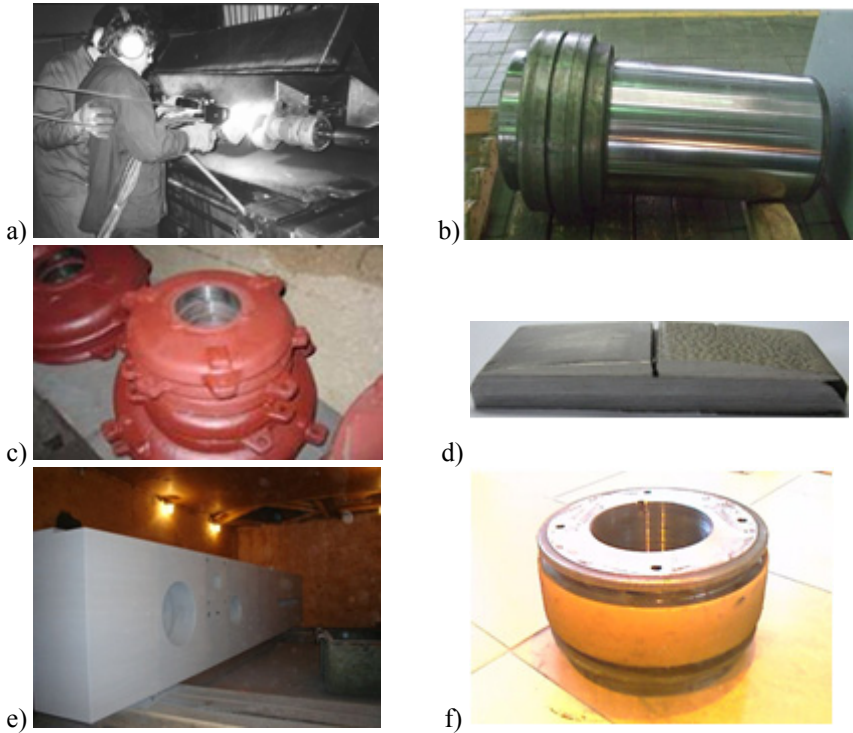


Figure 8: Examples of AAS application: a) the crankshaft of a KAMAZ heavy truck engine, service life at least run guarantee, steel core wire, 2.0 mm; b) plunger of press hydro cylinder, L 1090 mm,  $\varnothing$  657 mm, steel core wire, 2.5 mm; c) bearing housing of end shield, outer diameter up to 1200 mm, steel core wire, 3.0 mm; d) sample, friction coefficient less than at lined shell, Babbitt wire, 5 mm; e) plate for storage of exhausted fuel elements of nuclear reactor, Zn wire, 0.2 mm, f) piston of hydro cylinder,  $\varnothing$  280 mm, pressure 30 MPa, bronze wire, 5 mm. Courtesy of Russian companies: Avtoremzavod (Krasnoyarsk), TekchNaMet (Magnitogorsk), PermGlobalstroy servis (Perm), Mashprom (Ekaterinburg), Ural Welding Institute (Ekaterinburg).

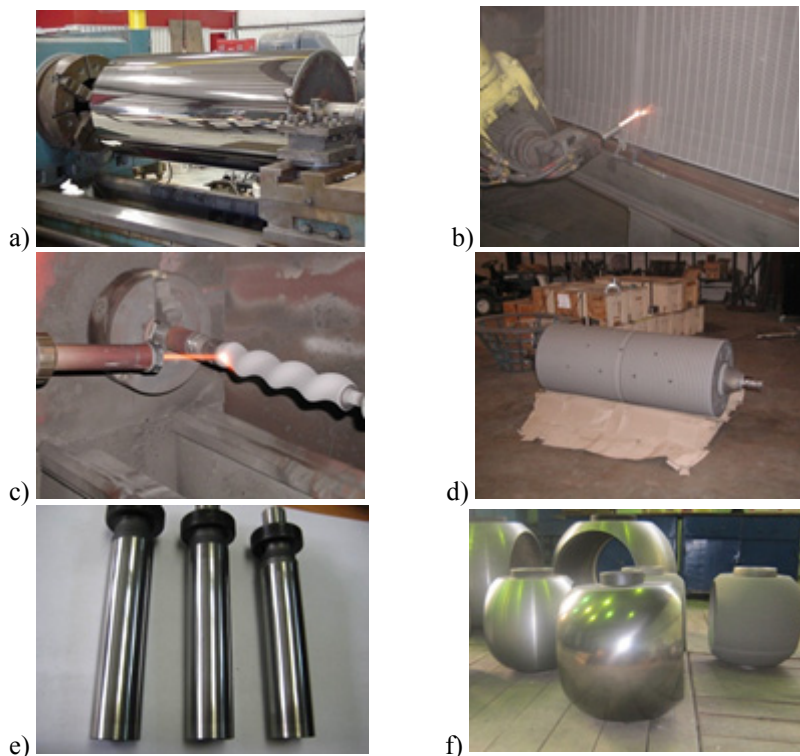


Figure 9: HVOF examples. a) film reel, WC-Co-Cr coating is superfinished to optical mirror range, i.e. Ra 0,010, galvanic chrome is replaced; b) separation screen for coal preparation at power plant, reducing abrasive wear by 8-fold compared with tempered ; c) rotor screw for pumping abrasive medium, hydro abrasive wear is lowered by 4 times vs. galvanic chrome; d) sink roll (metallurgy), exposed to corrosive attack from molten zinc; e) ball valve for oil transportation, exposed to abrasive and corrosive reagents,  $T > 600^{\circ}\text{C}$ , pressure  $> 130 \text{ MPa}$ ; f) plunger of hydro mechanical blasting plant, pressure 60 MPa, resource is increased by 3 times. Courtesy of Mashprom and Ural Welding Institute.

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